Coupled-Channel Final-State Interactions through Reggeon Exchange for $D(B) \to \pi\pi, K\bar{K}$

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Abstract

Coupled-channel final-state-interaction effects for D and B weak decays into $\pi\pi$ and $K\bar{K}$ are discussed in a Regge framework. It is found that the inclusion of coupled-channel effects significantly affects the results obtained previously in a quasi-elastic approximation. It is also shown that in the isospin $I = 0$ channel the inelastic final-state transitions $(\pi\pi)_{I=0} \to (K\bar{K})_{I=0}$ dramatically influence the phase of the $B^0 \to (K\bar{K})_{I=0}$ amplitude.

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Gathering data on CP-violation through detailed studies of nonleptonic decays of B mesons becomes one of the principal goals in our attempt to unravel the mystery of CP-violation. It is generally hoped that experimental results on nonleptonic B decays will provide information that will allow us to decide whether the standard model is correct or not. Unfortunately, extracting fundamental CP-violating parameters of the standard model from various B decay modes is not trivial at all. One of the main problems encountered is a reliable estimate of hadronic effects in the final state. Although such final-state-interaction (FSI) effects are often considered to be of no particular importance by themselves, their determination is crucial for the success of the whole project of extraction of fundamental CP-violating parameters.

In recent years several authors have stressed the importance of FSI in B decays [1]-[5]. Although there is a growing understanding that FSI must be taken into account, there are severe problems with their reliable treatment. Various approaches have been considered [6]-[8]. Usually only some intermediate states, believed to provide the largest effects, are taken into account. A Regge-model-based approach is often used here to estimate high-energy interactions between decay products. Recently, a simple model of this type has been applied to the description of strong phases in $D(B) \to K\pi$ and $D(B) \to \pi\pi$, $K\bar{K}$ decays [9, 10, 11].

The model of refs.[9, 10, 11] is based on a quasi-elastic approximation. This approximation considers rescatterings of the type: $K\pi \to K\pi$, $\pi\pi \to \pi\pi$, $K\bar{K} \to K\bar{K}$. All other possible final-state interactions are ignored. The model yields strong-interaction phases which compare favourably with the numbers extracted (with the help of some simplifying assumptions) from the existing experimental data at D mass [12], and predicts these phases at B mass. When assessing the reliability of these predictions, one may of course question the assumption of restricting the intermediate states to those composed of two pseudoscalar mesons only. However, even when one accepts that the contribution from these states dominates, or that the contribution from other states

simply follows the pattern of the PP contribution (P denotes a pseudoscalar meson), the question still remains whether the inelastic FSIs, ignored in [10, 11], modify their predictions in an essential way. Inelastic FSI means here the coupled-channel effects of the type $\pi\pi \to K\bar{K}$ or $K\pi \to K\eta$. Inclusion of such processes has been shown to be very important if a fully SU(3)-symmetric FSI-including effective-quark-diagram description of weak nonleptonic decays is to be achieved [4] (see also ref.[8]). In this paper we analyse in some detail the influence of coupled-channel effects on the predictions of the quasi-elastic Regge approach of ref. [10, 11]. In papers [10, 11] SU(3) symmetry was broken. Since our whole coupled-channel approach is calculationally simple only when SU(3) symmetry is unbroken, we will keep SU(3) symmetry throughout this paper. We will show, however, that in the no-coupled-channels case the original and SU(3)-symmetric versions of the model of ref.[11] do not differ much in their predictions. We will restrict ourselves to the noncharmed, nonstrange sector of two-meson interactions, i.e. to the analysis of coupled-channel effects in the $\pi\pi$, $K\bar{K}$, $\pi^0\eta_8$ and $\eta_8\eta_8$ channels. The latter two channels are included both because they are needed to maintain SU(3) symmetry of the analysis, and because the effects of these channels should be comparable to that of the $K\bar{K}$ channel (the mass of $\eta \approx \eta_8$ is close to that of the kaon).

Calculations within the Regge approach of refs. [10, 11] take into account the Pomeron and the exchange-degenerate Reggeons ρ, f_2, ω, and a_2. The contributions from non-Pomeron exchanges may be visualised with the help of quark diagrams of Fig.1, wherein the quark structure of Reggeons exchanged in the t-channel is seen. The contributions of diagrams (1a) and (1b) differ in their phases: diagram (1a) has phase $-\exp(-i\pi\alpha_R(t))$ with $\alpha_R(t) = 0.5 + \alpha' t$, $\alpha' \approx 1\ GeV^{-2}$ (for assumed SU(3) symmetry), while diagram (1b) has phase -1, i.e. is purely real, in agreement with the requirement of no exotic states in the s-channel.

For Cabibbo-suppressed D^0 decays there are six final PP states of interest

to us. In the basis of definite isospin these symmetrized two-boson states are:

$$\begin{aligned}
|(\pi\pi)_2\rangle &= \frac{1}{\sqrt{6}}(\pi^+\pi^- + \pi^-\pi^+ + 2\pi^0\pi^0) \\
|(K\bar{K})_1\rangle &= \frac{1}{2}(K^+K^- + K^-K^+ + K^0\bar{K}^0 + \bar{K}^0K^0) \\
|(\pi^0\eta_8)_1\rangle &= \frac{1}{\sqrt{2}}(\pi^0\eta_8 + \eta_8\pi^0) \\
|(\pi\pi)_0\rangle &= \frac{1}{\sqrt{3}}(\pi^+\pi^- + \pi^-\pi^+ - \pi^0\pi^0) \\
|(K\bar{K})_0\rangle &= \frac{1}{2}(K^+K^- + K^-K^+ - K^0\bar{K}^0 - \bar{K}^0K^0) \\
|(\eta_8\eta_8)_0\rangle &= \eta_8\eta_8
\end{aligned} \tag{1}$$

where the subscript in $|()_I\rangle$ denotes isospin I of the state. In terms of quark diagram amplitudes, the decays of D^0 to these states are given by

$$\begin{aligned}
\langle(\pi\pi)_2|w|D^0\rangle &= \frac{1}{\sqrt{6}}(a+b) \\
\langle(K\bar{K})_1|w|D^0\rangle &= \frac{1}{2}(a+c-e) \\
\langle(\pi^0\eta_8)_1|w|D^0\rangle &= \frac{1}{\sqrt{6}}(-b+c-e) \\
\langle(\pi\pi)_0|w|D^0\rangle &= \frac{1}{\sqrt{3}}(a-\frac{1}{2}b+\frac{3}{2}c+\frac{3}{2}e+3f) \\
\langle(K\bar{K})_0|w|D^0\rangle &= \frac{1}{2}(a+c-e-4f) \\
\langle(\eta_8\eta_8)_0|w|D^0\rangle &= \frac{1}{2}(-b+c-\frac{1}{3}e-2f)
\end{aligned} \tag{2}$$

where quark amplitudes are denoted by a (tree-level), b (colour-suppressed), c (W-exchange), e ("horizontal" penguin), f (Zweig-rule violating "vertical" penguin) [13].

For B^0 decays, we have analogously

$$\begin{aligned}
\langle(\pi\pi)_2|w|B^0\rangle &= -\frac{1}{\sqrt{6}}(a+b) \\
\langle(K\bar{K})_1|w|B^0\rangle &= \frac{1}{2}(c-e) \\
\langle(\pi^0\eta_8)_1|w|B^0\rangle &= \frac{1}{\sqrt{6}}(c-e) \\
\langle(\pi\pi)_0|w|B^0\rangle &= -\frac{1}{\sqrt{3}}(a-\frac{1}{2}b+\frac{3}{2}c+\frac{3}{2}e+3f)
\end{aligned}$$

$$
\begin{aligned}
\langle (K\bar{K})_0|w|B^0\rangle &= \frac{1}{2}(c+e+4f) \\
\langle (\eta_8\eta_8)_0|w|B^0\rangle &= \frac{1}{6}(b+c+e+6f)
\end{aligned} \tag{3}
$$

with amplitudes a (tree), b (colour-suppressed), c (W-exchange), etc. different from those in D decays.

In Eq.(2) we assumed SU(3) symmetry in weak decays, i.e. equal amplitudes for the production of strange ($s\bar{s}$) and nonstrange quark pairs. Below we will estimate Pomeron and non-leading Reggeon contributions both without and with coupled-channel effects.

There are three separate non-communicating sectors of different isospin (I=0,1,2). Let us first discuss the contributions of exchange-degenerate SU(3)-symmetric Reggeons. The numerical factors describing the strength of various transitions are computed by sandwiching diagrams of Fig.1 (denoted below by C for crossed diagrams and U for uncrossed ones) in between the states of Eq.(1).

In the I=2 sector one obtains (the second equality essentially defines our normalization convention)

$$
\begin{aligned}
\langle (\pi\pi)_2|U_2|(\pi\pi)_2\rangle &= 0 \\
\langle (\pi\pi)_2|C_2|(\pi\pi)_2\rangle &= 2
\end{aligned} \tag{4}
$$

i.e. there is only a contribution from the crossed diagram of Fig.1b.

In the I=1 sector there are two states $(K\bar{K})_1$ and $(\pi^0\eta_8)_1$, and, consequently, we have coupled-channel effects described together with quasi-elastic effects by two 2x2 matrices. For the uncrossed exchanges we have the matrix

$$
\mathbf{U}_1 = [\langle i|\mathbf{U}_1|j\rangle] = \begin{bmatrix} \epsilon^2 & \sqrt{\frac{2}{3}}\epsilon \\ \sqrt{\frac{2}{3}}\epsilon & \frac{2}{3} \end{bmatrix} \tag{5}
$$

while for the crossed exchanges we have

$$
\mathbf{C}_1 = [\langle i|\mathbf{C}_1|j\rangle] = \begin{bmatrix} 0 & -2\sqrt{\frac{2}{3}}|\epsilon| \\ -2\sqrt{\frac{2}{3}}|\epsilon| & \frac{2}{3} \end{bmatrix} \tag{6}
$$

The states in the rows and columns are (from top to bottom and from left to right): $i, j = (K\bar{K})_1$ and $(\pi^0\eta_8)_1$. The parameter ϵ is introduced for completeness and clarification: entries proportional to ϵ or ϵ^2 arise from the propagation of one or two strange (anti)quarks in the t-channel. For our SU(3)-symmetric discussion of coupled-channel effects we shall later take $\epsilon = 1$.

In the I=0 sector the resulting 3x3 matrix for uncrossed exchanges is:

$$\mathbf{U}_0 = [\langle i|\mathbf{U}_0|j\rangle] = \begin{bmatrix} 3 & -\sqrt{3}\epsilon & -\frac{1}{\sqrt{3}} \\ -\sqrt{3}\epsilon & 2+\epsilon^2 & \frac{5}{3}\epsilon \\ -\frac{1}{\sqrt{3}} & \frac{5}{3}\epsilon & \frac{1+8\epsilon^2}{9} \end{bmatrix}, \tag{7}$$

while for the crossed exchanges we have

$$\mathbf{C}_0 = [\langle i|\mathbf{C}_0|j\rangle] = \begin{bmatrix} -1 & 0 & -\frac{1}{\sqrt{3}} \\ 0 & 0 & -\frac{4}{3}|\epsilon| \\ -\frac{1}{\sqrt{3}} & -\frac{4}{3}|\epsilon| & \frac{1+8|\epsilon|^2}{9} \end{bmatrix} \tag{8}$$

with the rows and columns corresponding to the states $(\pi\pi)_0$, $(K\bar{K})_0$, and $(\eta_8\eta_8)_0$ (from top to bottom and from left to right).

The relevant $A((PP)_I)$ amplitudes are obtained by multiplying the entries of Eqs.(4-8) by an appropriate Regge phase and by a factor $Rs^{\alpha_R(t)}$, where R is the Regge residue fitted from experiment:

$$R = -4g^2(\omega, KK) = -\frac{4}{9}g^2(\omega, pp) = -13.1 \text{ mb} \tag{9}$$

with $g^2(\omega, pp)$ extracted from ref.[14]. The residues of ρ, ω etc. Reggeons obtained in this way from Eqs.(4-8) satisfy the condition of SU(3) symmetry. It is known that this is a good assumption. For the trajectories themselves SU(3) is not such a good approximation. Nonetheless, we will accept it when estimating coupled-channel effects since it dramatically simplifies the discussion.

Calculations of refs.[11] correspond to considering only diagonal entries in the matrices of Eqs.(5-8) and then putting $\epsilon = 0$. When one takes into account the Pomeron contribution as well, the complete amplitudes without the coupled-channel effects are given (as in [11]) by:

$$
\begin{aligned}
A((\pi\pi)_2) &= i\beta_P(\pi\pi)e^{2b_P^\pi t}s + 2Rs^{\alpha_R(t)} \\
A((\pi\pi)_0) &= i\beta_P(\pi\pi)e^{2b_P^\pi t}s + R(3e^{-i\pi\alpha_R(t)} - 1)s^{\alpha_R(t)} \\
A((K\bar{K})_1) &= i\beta_P(KK)e^{2b_P^K t}s + Re^{-i\pi\alpha_R(t)}s^{\alpha_R(t)}\epsilon^2 \\
A((K\bar{K})_0) &= i\beta_P(KK)e^{2b_P^K t}s + R(2+\epsilon^2)e^{-i\pi\alpha_R(t)}s^{\alpha_R(t)} \qquad (10)
\end{aligned}
$$

For D or B decays one needs the projection of Regge amplitudes on the s-channel $l = 0$ partial wave. This amounts to integrating Regge amplitudes over t from $t = 0$ to $-s$. With good accuracy, the Pomeron contribution is then proportional to $\beta_P(\pi\pi)/(2b_P^\pi)$ for $(\pi\pi)_{0,2}$ channels and $\beta_P(KK)/(2b_P^K)$ for $(K\bar{K})_{0,1}$ channels. Comparison with [10, 11] yields:

$$
\frac{\beta_P(\pi\pi)}{2b_P^\pi} \cdot \frac{2b_P^K}{\beta_P(KK)} = \frac{2\beta_P(0)}{3b_P} \cdot \frac{2\tilde{b}_P}{\tilde{\beta}_P(0)} = \frac{8}{3}\frac{x_{\pi\pi}}{x_{K\bar{K}}} \approx 1.1(\pm 0.3) \qquad (11)
$$

where the two entries in between the three equality signs relate our parameters to the corresponding parameters of ref.[11]. We conclude therefore that it should be reasonable to use SU(3) symmetry for the Pomeron contribution as well.

Using

$$
\frac{\beta_P(\pi\pi)}{2b_P^\pi} = \frac{\beta_P(KK)}{2b_P^K} = \frac{9.9 \text{ mb}}{2.75 \text{ GeV}^{-2}} = 3.6 \text{ mb GeV}^2 = P \qquad (12)
$$

the calculations of the s-channel $l = 0$ partial waves $a((PP)_I)$ give (as in [11])

$$
\begin{aligned}
a((\pi\pi)_2) &= iP + \frac{2R}{\alpha'}\frac{s^{-1/2}}{\ln s} \\
a((\pi\pi)_0) &= iP - \frac{R}{\alpha'}\left(\frac{3is^{-1/2}(\ln s + i\pi)}{\ln^2 s + \pi^2} + \frac{s^{-1/2}}{\ln s}\right) \\
a(K\bar{K})_1) &= iP + \frac{R}{\alpha'}\frac{\epsilon^2 is^{-1/2}(\ln s + i\pi)}{\ln^2 s + \pi^2} \\
a((K\bar{K})_0) &= iP - \frac{R}{\alpha'}\frac{(2+\epsilon^2)is^{-1/2}(\ln s + i\pi)}{\ln^2 s + \pi^2}. \qquad (13)
\end{aligned}
$$

In ref.[11] the effects of FSI on weak decay amplitudes are estimated through multiplying quark-level amplitudes by hadronic phase factors, while completely

neglecting different possible hadronic renormalization of quark-level amplitudes of different isospin. In the calculations of this paper we shall follow this line of reasoning to see how coupled-channel effects *alone* modify the results of ref.[11]. Using $s = m_D^2 = 3.47\ \mathrm{GeV}^2$ in Eq.(13) one finds the phases given in columns 3, 4 of Table 1. It is column 3 which should be directly compared with the results of ref.[11] (quoted in column 2 of Table 1): columns 2 and 3 differ only by our simplifying assumption of SU(3) for the Pomeron amplitudes. One can see that this assumption is reasonable: our results are close to those of ref.[11]. Column 4 includes effects of ϕ Reggeon exchanges (assuming SU(3)) which reduce the $|\delta_K^1 - \delta_K^0|$ phase difference. The phase shift in $P\bar{P}$ channel of isospin I is denoted by δ_P^I.

TABLE 1

Comparison of calculated values of phase shifts for D decays

phase	no coupled channels			"experiment"	coupled channels	
	ref.[11]	Eq.(13)		ref.[12]	$c, e, f = 0$	
		$\epsilon = 0$	$\epsilon = 1$		r=1	r=-1.8
δ_π^2		162^o	162^o		162^o	162^o
δ_π^0		92^o	92^o		60^o	52^o
$\delta_\pi^2 - \delta_\pi^0$	$60^o \pm 4^o$	70^o	70^o	$82^o \pm 10^o$	102^o	110^o
δ_K^1		90^o	114^o		111^o	78^o
δ_K^0		127^o	138^o		111^o	78^o
$\delta_K^1 - \delta_K^0$	$-29^o \pm 4^o$	-37^o	-24^o	$\pm(24^o \pm 13^o)$	0^o	0^o

Let us now discuss the coupled-channel effects. We will assume from now on that $\epsilon = 1$. In a sector of given isospin I, the matrices $\mathbf{U}_I$ and $\mathbf{C}_I$ commute. Consequently, we may diagonalize them simultaneously.

In the $I = 0$ sector the eigenvectors of $\mathbf{U}_0$ and $\mathbf{C}_0$ are

$$|\mathbf{1}, 0\rangle \;\; = \;\; \frac{1}{2\sqrt{2}}(-\sqrt{3}|(\pi\pi)_0\rangle + 2|(K\bar{K})_0\rangle + |(\eta_8\eta_8)_0\rangle)$$

$$
\begin{aligned}
|\mathbf{8},0\rangle &= \frac{1}{\sqrt{5}}(\sqrt{3}|(\pi\pi)_0\rangle + |(K\bar{K})_0\rangle + |(\eta_8\eta_8)_0\rangle) \\
|\mathbf{27},0\rangle &= \frac{1}{\sqrt{10}}(\frac{1}{2}|(\pi\pi)_0\rangle + \sqrt{3}|(K\bar{K})_0\rangle - \frac{3\sqrt{3}}{2}|(\eta_8\eta_8)_0\rangle)
\end{aligned} \tag{14}
$$

with eigenvectors labelled by the relevant SU(3) representation.

In the $I = 1$ sector the eigenvectors of $\mathbf{U}_1$ and $\mathbf{C}_1$ are

$$
\begin{aligned}
|\mathbf{8},1\rangle &= \frac{1}{\sqrt{5}}(\sqrt{3}|(K\bar{K})_1\rangle + \sqrt{2}|(\pi^0\eta_8)_1\rangle) \\
|\mathbf{27},1\rangle &= \frac{1}{\sqrt{5}}(-\sqrt{2}(K\bar{K})_1 + \sqrt{3}(\pi^0\eta_8)_1).
\end{aligned} \tag{15}
$$

In the $I = 2$ sector there is only one state, the $|\mathbf{27},2\rangle = |(\pi\pi)_2\rangle$.

The eigenvalues corresponding to these eigenvectors are

$$
\begin{aligned}
|\mathbf{1}, I=0\rangle \rightarrow \quad & \lambda_U = \tfrac{16}{3} \quad \lambda_C = -\frac{2}{3} \\
|\mathbf{8}, I=0,1\rangle \rightarrow \quad & \lambda_U = \tfrac{5}{3} \quad \lambda_C = -\frac{4}{3} \\
|\mathbf{27}, I=0,1,2\rangle \rightarrow \quad & \lambda_U = 0 \quad \lambda_C = 2.
\end{aligned} \tag{16}
$$

Amplitudes $a(\mathbf{27}, I)$ in the $I = 0, 1, 2$ sectors are all equal. Similarly, amplitudes $a(\mathbf{8}, I)$ in $I = 0, 1$ sectors are equal. Thus, one obtains the following three different FSI amplitudes

$$
\begin{aligned}
a(\mathbf{1}) &= iP - \frac{R}{\alpha'}\left(\frac{16}{3}\frac{is^{-1/2}(\ln s + i\pi)}{\ln^2 s + \pi^2} + \frac{2}{3}\frac{s^{-1/2}}{\ln s}\right) \\
a(\mathbf{8}) &= iP - \frac{R}{\alpha'}\left(\frac{5}{3}\frac{is^{-1/2}(\ln s + i\pi)}{\ln^2 s + \pi^2} + \frac{4}{3}\frac{s^{-1/2}}{\ln s}\right) \\
a(\mathbf{27}) &= iP + \frac{2R}{\alpha'}\frac{s^{-1/2}}{\ln s}.
\end{aligned} \tag{17}
$$

The amplitude $a(\mathbf{27})$ must be of course equal to $a((\pi\pi)_2)$ in Eq.(13)

Due to coupled-channel effects, the observed FSI-corrected weak decay amplitudes $\langle(\pi\pi)_0|W|D^0\rangle$, $\langle(K\bar{K})_0|W|D^0\rangle$, and $\langle(\eta_8\eta_8)_0|W|D^0\rangle$ become linear combinations of appropriate short-distance quark-level amplitudes in Eq.(2), i.e.:

$$
\langle(PP)_I|W|D^0\rangle = \sum_{\mathbf{R}}\langle(PP)_I|\mathbf{R},I\rangle\langle\mathbf{R},I|S_{FSI}|\mathbf{R},I\rangle\langle\mathbf{R},I|w|D^0\rangle \tag{18}
$$

with $\langle (PP)_I|\mathbf{R}, I\rangle$ given in Eqs.(14,15), $\langle \mathbf{R}, I|S_{FSI}|\mathbf{R}, I\rangle$ describing SU(3)-symmetric final state interactions in the $|\mathbf{R}, I\rangle$ state, and $\langle \mathbf{R}, I|w|D^0\rangle$ determined from Eqs.(2,14,15).

In line with the spirit of ref.[11] and as a simple example we assume now that the FSI-corrected weak decay amplitudes $\langle \mathbf{R}, I|W|D^0\rangle = \langle \mathbf{R}, I|S_{FSI}|\mathbf{R}, I\rangle \cdot \langle \mathbf{R}, I|w|D^0\rangle$ differ from quark-level expressions ($\langle \mathbf{R}, I|w|D^0\rangle$) by hadronic phase factors $\exp(i\delta(\mathbf{R}))$ only, i.e. that the possible hadron-level renormalization of the *magnitude* of short-distance amplitudes is negligible. Although in general this assumption need not be true, its violation will not change the qualitative conclusions of this paper.

Within the considered model the phases are determined from Eq.(17). At $s = m_D^2 = 3.47$ GeV^2 one gets $\delta(\mathbf{1}) = 130^o$, $\delta(\mathbf{8}) = 49^o$, and $\delta(\mathbf{27}) = 162^o$. Even with the simplifying assumption of no FSI-induced change of magnitudes of short-distance amplitudes, in order to estimate how the quark-level amplitudes a, b, c etc. add up, one has to make additional assumptions about their actual size. Usually, one assumes that the factorization amplitudes a and b dominate, thus neglecting the contribution from diagrams c, e, and f. Below we shall discuss two most often considered cases: 1) "bare" quark-level relation $a = 3b$ and 2) QCD-corrected relation $a = 3rb$ with $r \approx -1.8$ [13, 15, 16]. Then, all amplitudes are given in terms of a single parameter a, the size of which is irrelevant when determining phase shifts. We see from Table 1 that the SU(3)-symmetric treatment of coupled-channel effects leads to vanishing $\delta_K^1 - \delta_K^0$ phase-shift difference. This is in fact true for any a, b, c, provided e and f vanish (see also ref.[4]). Comparing appropriate columns in Table 1 we see that the inclusion of coupled-channel effects dramatically changes hadronic phase-shift differences in the considered model: $\delta_\pi^2 - \delta_\pi^0 = 70^o \to \approx 110^o$, $\delta_K^1 - \delta_K^0 \approx -30^o \to 0^o$.

One may ask if similar strong dependence on coupled-channel effects could occur in B-decays. For the sake of comparison, we need the phase shifts cal-

culated without coupled-channel effects. These phase shifts are given on the left-hand side of Table 2.

TABLE 2

Comparison of calculated values of phase shifts for B decays

phase	no coupled channels			coupled channels		
	ref.[11]	Eq.(13)			$b = a/(3r)$, $r = -3$	
		$\epsilon = 0$	$\epsilon = 1$	$e \gg a, b$	$e = 0.2a$	$e = 0.04a$
δ_π^2		112^o	112^o	112^o	112^o	112^o
δ_π^0		94^o	94^o	98^o	94^o	93^o
$\delta_\pi^2 - \delta_\pi^0$	$+11^o \pm 2^o$	18^o	18^o	14^o	18^o	19^o
δ_K^1		90^o	83^o	85^o	85^o	85^o
δ_K^0		100^o	103^o	110^o	137^o	168^o
$\delta_K^1 - \delta_K^0$	$-7^o \pm 1^o$	-10^o	-20^o	-25^o	-52^o	-83^o

If the coupled-channel effects are taken into account, at $s = m_B^2$ we obtain from Eq.(17) the following phase shifts for different SU(3) channels: $\delta(\mathbf{1}) = 104^o$, $\delta(\mathbf{8}) = 85^o$, $\delta(\mathbf{27}) = 112^o$.

In order to estimate how the considered coupled-channel effects affect phase-shift values given in the left-hand side of Table 2, we must again make some assumptions about the relative size of short-distance amplitudes a, b, etc. at $s = m_B^2$. One expects that the dominant contribution is provided by the a amplitude and that the amplitudes b and e constitute a 10-20% correction [17]. Contributions from other amplitudes are expected to be much smaller [17]. Using $r = (c_1 + c_2/3)/(3c_2 + c_1) \approx -3$, assuming e/a in the range of $0.04 - 0.20$ (as estimated in [18]), and neglecting other contributions in Eq.(3), we can estimate the FSI phases in B-decays. Using the procedure of Eq.(18) for B decays one then obtains the numbers given in the right-hand side of Table 2.

We see from Table 2 that the phases in $(\pi\pi)_I$ channels do not depend very strongly on the inclusion of coupled-channel effects. This is also the case for

the $(K\bar{K})_1$ phase. In fact, the latter phase is always equal to $\delta(\mathbf{8})$ because the $|\mathbf{27},1\rangle$ state is not produced in the weak B^0 decay (see Eqs.(3,15)). However, the $(K\bar{K})_0$ phase changes dramatically when coupled-channel effects are included. Only for $a, b \ll e$ the phase change induced by coupled-channel effects is small. However, if e is small the relevant phase change is large. The origin of this effect can be understood from Eqs.(3): due to coupled-channel effects, the $(\pi\pi)_0$ state created in a short-distance decay process may be converted into a $(K\bar{K})_0$ final state. Thus, the observed final $(K\bar{K})_0$ state receives contribution from both the short-distance $B^0 \to (K\bar{K})_0$ decay (characterized by small amplitude e) with $(K\bar{K})_0$ elastically scattered into the final $(K\bar{K})_0$ state, as well as from the short-distance $B^0 \to (\pi\pi)_0$ decay (characterized by large amplitude a) which contributes through coupled-channel rescattering effects into the final $(K\bar{K})_0$ state. The net result is interference of the small e amplitude with some admixture coming from the large a amplitude. If the relative absolute size of the two contributions is comparable, one can obtain a wide range of phases for their sum. This lies at the origin of large phases in the $(K\bar{K})_0$ channel of B^0 decays (Table 2). Thus, in spite of a relative weakness (as compared to elastic rescattering) of strangeness-exchanging Reggeon contribution (which induces $(\pi\pi)_0 \to (K\bar{K})_0$) at $s = m_B^2$, the generated FSI phase may be large.

The above mechanism of generating large FSI phases in $B^0 \to (K\bar{K})_0$ decays must also work when the two simplifying assumptions of 1) SU(3) symmetry, and 2) no renormalization of amplitude magnitudes, are somewhat broken. With SU(3) symmetry broken, one would expect results somewhere in between those on the left- and right-hand sides of Table 2. In fact, the mechanism under discussion should be operative, provided there is a small FSI transition $(\pi\pi)_0 \to (K\bar{K})_0$, since, as shown in Fig.1c, such a transition generates an effective large-distance penguin amplitude interfering with the original short-distance penguin. Of course, intermediate states other than $\pi\pi$ may also contribute in a similar way to the final $(K\bar{K})_0$ state. Furthermore, the use of Regge amplitudes for $l = 0$ may be also questioned. All this cannot change, however,

our general expectation that in explicit models for $B^0 \to (K\bar{K})_0$ decays it is quite likely to obtain large long-distance-induced phases.

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References

[1] J. F. Donoghue, Phys. Rev. D33, 1516 (1986).

[2] L. Wolfenstein, Phys. Rev. D52, 537 (1995).

[3] J. F. Donoghue et al., Phys. Rev. Lett. 77, 2178 (1996).

[4] P. Żenczykowski, Acta Phys. Pol. B28, 1605 (1997).

[5] M. Neubert, Phys. Lett. B424, 152 (1998).

[6] M. Ciuchini, E. Franco, G. Martinelli, L. Silvestrini, Nucl. Phys. B501 (1997) 271; D. Atwood, A. Soni, Phys. Rev. D58 (1998) 036005.

[7] C. Smith, hep-ph/9808376, "SU(N) Elastic Rescattering in B and D Decays".

[8] M. Gronau, J. L. Rosner, Phys. Rev. D58 (1998) 113005.

[9] J.-M. Gérard, J. Weyers, Eur. Phys. J. C7, 1 (1999).

[10] D. Delépine, J.-M. Gérard, J.Pestieau, J. Weyers, Phys. Lett. B429, 106 (1998).

[11] J.-M. Gérard, J. Pestieau, J. Weyers, Phys. Lett. B436, 363 (1998).

[12] M. Bishai et al., CLEO Collaboration, Phys. Rev. Lett. 78, 3261 (1997); M. Selen et al., CLEO Collaboration, Phys. Rev. Lett. 71, 1973 (1973).

[13] L.-L. Chau, H.-Y. Cheng, Phys. Rev. D36, 137 (1987).

[14] V. Barger, R. J. N. Phillips, Nucl. Phys. B32, 93 (1971).

[15] C.Sorensen, Phys. Rev. D23, 2618 (1981).

[16] A. N. Kamal, E. D. Cooper, Z. Phys. C8, 67 (1981).

[17] M. Gronau, O. F. Hernandez, D. London, J. L. Rosner, Phys. Rev. D52, 6356 (1995).

[18] M. Gronau, Phys. Lett. B300, 163 (1993).

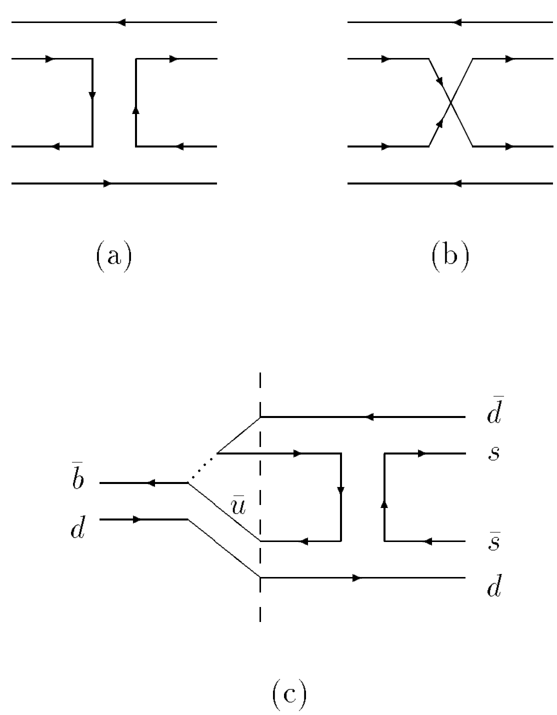

Fig.1. Quark line diagrams:
(a) Uncrossed Reggeon exchange
(b) Crossed Reggeon exchange
(c) Contribution to $(\pi\pi)_0 \to (K\bar{K})_0$ final-state interaction